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Indian Standard

SPECIFICATION FOR RADIATION DETECTORS FOR INSTRUMENTATION AND PROTECTION OF NUCLEAR REACTORS

(IEC Title : Radiation Detectors for the Instrumentation and Protection of Nuclear Reactors Characteristics and Test Methods)

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NEW DELHI 110002

Gr 9

October 1987

Indian Standard

SPECIFICATION FOR RADIATION DETECTORS FOR INSTRUMENTATION AND PROTECTION OF NUCLEAR REACTORS

(IEC Title : Radiation Detectors for the Instrumentation and Protection of Nuclear Reactors; Characteristics and Test Methods)

National Foreword

This Indian Standard, which is identical with IEC Pub 515 (1975) 'Radiation detectors for the instrumentation and protection of nuclear reactors; characteristics and test methods' issued by the International Electrotechnical Commission, was adopted by the Indian Standards Institution on the recommendation of the Nuclear Instrumentation Sectional Committee and approval of the Electronics and Telecommunication Division Council.

Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'Indian Standard'.

Cross References

In this Indian Standard, the following International Standards are referred to. Read in their respective places the following:

International Standard	*Corresponding Indian Standard*
IEC Pub 50(66) (1968) Detection and measurement of ionizing radiation by electric means [Superseded by IEC Pub 50(391) and 50(392)] IEC Pub 50(391) (1975) Detection and measurement of ionizing radiation by electric means	IS : 1885 (Part 63)-1985 Electrotechnical vocabulary: Part 63 Nuclear instrumentation

The technical committee responsible for the preparation of this Indian Standard has reviewed the provisions of the following IEC standards and decided that they are acceptable for use in conjuction with this standard.

IEC Pub 231 (1967) General principles of nuclear reactor instrumentation

IEC Pub 232 (1966) General characteristics of nuclear reactor instrumentation

Only the English language text of the International Standard has been retained while adopting it in this Indian Standard.

Nuclear Instrumentation Sectional Committee, LTDC 26 [Ref : Doc : LTDC 26 (932)]

Adopted 28 August 1985 | Gr 9

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SECTION ONE — INTRODUCTION

1. Scope

The aim of this publication is to establish a standard concerning the characteristics and test methods of gas-filled radiation detectors used for the instrumentation and protection of nuclear reactors.

These detectors function as electrical transducers and are used particularly in:

— assemblies for measuring power and rate of change of power by means of neutron fluence rate (flux);

— periodmeters or reactivity meters;
— reactor warning and safety monitoring assemblies;
— assemblies for measuring power by means of gamma radiation.

The detectors examined in this standard are not used for personnel dosimetry purposes.

In so far as they do not conflict with the present standard, IEC Publication 231, General Principles of Nuclear Reactor Instrumentation, and IEC Publication 232, General Characteristics of Nuclear Reactor Instrumentation, should be followed, as well as general recommendations and safety standards for electrical equipment which have already been issued.

The detectors subject to this standard are:

— boron current ionization chambers;
— fission current ionization chambers or pulse ionization chambers;
— ionization chambers for gamma radiation;
— boron trifluoride proportional counter tubes;
— boron-lined proportional counter tubes;
— helium-3 proportional counter tubes.

Note. — This list is not restrictive and it is hoped that all types of radiation detectors used in reactor installations will benefit from the present standard. The standard for tests also applies to connecting cables and connectors when they form an integral part of the detector.

2. Definitions

Preliminary note

Definitions given in Sub-clauses 2.1, 2.2 and 2.4 to 2.9 are taken from or based on IEC Publication 50(391), Detection and Measurement of Ionizing Radiation by Electric Means. The other definitions are still under consideration and given here to facilitate understanding of this standard.

2.1 *Concomitant radiation*

Radiation which is associated with the radiation to be measured but which is not the object of the measurement, and whose effects on the measurement should preferably be eliminated.

2.2 *Sensitivity (of a measuring assembly)*

For a given value of the measured quantity, the ratio of the increase of the observed variable to the corresponding increase of the measured quantity.

$$S = \frac{\text{variation of output quantity (detector response)}}{\text{variation of input quantity (radiation to be measured)}}*$$

2.3 *Influenceability*

If the operation of a detector is disturbed by a concomitant radiation, the detector is said to be "influenceable" by this other radiation. The concomitant radiation is an influence quantity.

The influenceability of a detector to concomitant radiation is given by:

$$S = \frac{\text{variation of the output quantity (detector response)}}{\text{variation of the input quantity (concomitant radiation)}}*$$

with all other influence quantities held constant at specified values. Other factors such as temperature, pressure, polarizing potential, etc., may also be influence quantities.

2.4 *Compensation factor (of a compensated ionization chamber)*

The ratio of the sensitivity to concomitant radiation of the compensated ionization chamber to the sensitivity to the same concomitant radiation of the same chamber, if it were not compensated.

2.5 *Compensation ratio (of a compensated ionization chamber)*

The inverse of the *compensation factor* used as an index of performance of a *compensated ionization chamber.*

2.6 *Sensitive material (of a neutron detector)*

The material used in certain neutron detectors either, for example, in a lining or a filling gas, which is intended to produce *directly ionizing* particles from the neutrons by nuclear reaction.

Note. — The word "particle" is used here in a general sense including *fission fragments.*

2.7 *Burn-up life (of a neutron detector)*

An estimated *fluence* of *neutrons* of a given energy distribution after which the *sensitive material* will be consumed to such an extent that the detector characteristics exceed the specified tolerances for a specified purpose.

2.8 *Useful life (of a detector)*

Operational life, under irradiation and environmental conditions restricted within specified limits, after which the detector characteristics exceed the specified tolerances. Useful life can be expressed in incident particle *fluence*, number of produced pulses, etc.

2.9 *(Particle) fluence rate (particle flux density)*

Increment of fluence $\Delta\ \Phi$ during a suitably small interval of time $\Delta\ t$ divided by that interval of time.

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* In many applications where the detector has a linear characteristic and negligible output for zero input

$$S = \frac{\text{output quantity}}{\text{input quantity}}$$

Symbol: φ

$$\varphi = \frac{\Delta \Phi}{\Delta t}$$

Note. — Fluence rate is identical with the product of the volume particle density and the average speed.

2.10 *Unperturbed neutron fluence rate (flux)*

Mean neutron fluence rate in a position without the neutron detector placed in the same position.

2.11 *Perturbed neutron fluence rate (flux)*

Spatial mean neutron fluence rate in a position with the neutron detector placed in the same position for measurement. This quantity is equal to the detector output divided by its sensitivity and is, in practice, approximated by the neutron fluence rate averaged over the detector surface.

3. Interpretation of this standard

The verbs listed below have the following implications in this standard:

Mandatory: "shall" or "must".

Recommendation: "should".

Permissible: "may".

SECTION TWO — PRELIMINARY

4. General

Although each category of detector and each type of apparatus has its own particular conditions of use and range of application, it is possible to define general principles of use which depend essentially on the following:

a) the intrinsic characteristics of each type of detector;

b) the limitations resulting indirectly from the quantity measured, e.g. activation of the materials by neutrons;

c) the measuring sub-assembly used, the characteristics of which must be suited to those of the detector;

d) the characteristics of the medium surrounding the detector and particularly the influence quantities.

The mode of use of the ionization produced must be defined: the pulse mode, the direct current mode and the mean square or variance current mode are examples.

If detectors are operated in more than one mode, their characteristics shall be given for each mode.

5. Types of radiation to be measured

The two principal types of radiation to be measured are neutrons and photons. They are represented by neutron fluence rate (flux) in the first case and by either the absorbed dose rate or the exposure rate in the second case.

Each detector is preferably constructed to measure one single kind of radiation but it is almost always influenced by other radiations which surround it. This means:

— the superposition on the measurement of a background which impairs accuracy and can reduce the range of measurement;

— if the influence of the concomitant radiation becomes significant, the radiation to be measured may be obscured. In particular, residual gamma radiation often impairs the measurement of neutrons.

All radiation in the detector environment has to be considered in the conditions of use. The characteristics may be altered by activation of the detector materials by neutrons, the release of heat by the absorption of radiation and therefore changes in material properties, or by other changes to the filling gas.

6. Detector operating conditions

Detectors placed in or near the core of reactors are subject to very stringent design regulations, particularly with reference to the materials used.

The variables which impose a limitation on the use of detectors should be specified together with their limits for each type of detector.

The significant variables, in general, are neutron fluence rate (flux) and spectrum, environmental temperature, pressure, humidity, etc.

7. Conditions of detector measurement

Measuring conditions are characterized mainly by the following:

— a large range of measurement (often of the order of six to ten decades);

— the severity of the ambient conditions due to high-flux values, a high intensity of concomitant radiation and high pressures and temperatures;

— the activation of materials, often resulting in replacement difficulties even when the reactor is shut down.

7.1 *Limits due to the detector*

For an ionization chamber, the upper limit of the measuring range is set by the rate of recombination of ions causing deviation from proportionality between the neutron fluence rate (flux) and the output signal.

This upper limit of the measuring range may be determined by a specified deviation from proportionality for a given polarization voltage or by the output current at which a given ratio or difference between $U_{1.1}$ and $U_{0.9}$ is obtained (see Sub-clause 16.4.1).

For pulse detectors, an absolute upper limit to the measuring range is set by the resolving time of the detector together with its associated measuring assembly.

The intrinsic lower limit of the measuring range is determined by the output signal in the absence of the primary ionizing radiation under given ambient conditions.

It is desirable not to exceed a given value of the neutron fluence rate (flux) beyond which activation of materials would produce a gamma or beta background large enough to make subsequent low-level measurements difficult.

An important case is that of highly sensitive detectors used for reactor start-up (in particular boron trifluoride or boron-lined counter tubes) where the activity of materials may be prejudicial to immediate re-use.

7.2 *Limits due to the measuring sub-assembly*

The limits due to the measuring sub-assembly are determined essentially by the resolving time, bandwidth, noise level and input impedance in the case of pulse measuring systems, and by the current sensitivity, drift, zero offset and input impedance in the case of current measuring sub-assemblies.

7.3 *Limits due to surrounding gamma radiation*

Frequently, the surrounding gamma radiation imposes a lower limit in the use of detectors. Gamma radiation generates spurious ionization current in current ionization chambers and modifies the counting plateau to give false counts in ionization pulse chambers. This limit can be lowered in neutron current ionization chambers by compensation, and in pulse fission chambers by reduction of the chamber and amplifier assembly resolving time. Improvements can also be made by suitably shielding the detector against gamma radiation.

In the particular case of boron current ionization chambers, the lower limit imposed by gamma radiation is relatively high. When the chambers are compensated, the lower limit of practical use can be calculated with the following relation:

$$\varphi_{\min} = \frac{f}{e} \frac{S_\gamma}{S_n} X$$

in which:

$\varphi_{\min}$ = minimum neutron fluence rate (flux) measurable with the required accuracy

e = required maximum ratio of the gamma current to neutron current expressed as a percentage (%)

f = compensation factor expressed as a percentage (%)

S_n = sensitivity of the chamber to neutron radiation in amperes per unit of neutron flux density ($A \cdot n^{-1} \cdot cm^2 \cdot s$)

S_γ = influenceability of the chamber to gamma radiation without compensation, in amperes per unit of exposure rate ($A \cdot R^{-1} \cdot h$)

X = exposure rate ($R \cdot h^{-1}$)

In some designs, the compensation factor can be changed, for example by adjusting the compensation voltage.

The compensation factor can depend on the intensity of the radiation γ and its energy spectrum. The compensation should therefore allow for variation in conditions with respect to the gamma radiation source and the source to detector geometry.

8. Connectors and cables

Connectors and cables are often an integral part of a detector assembly and should be designed so as not to limit detector performance.

The design of connectors and cables should enable them to be easily manipulated by hand or by remote handling devices without risk of damage.

Care should be taken in particular to avoid electrical interference which could interfere with the operation of measuring sub-assemblies. To reduce electrical interference, detectors may need to be electrically shielded and the outer shield insulated from the common side of the measuring circuit and from electrical contact whith the external frame (for example see IEC Publication 232).

It is also necessary to ensure the continuity of connections and it is desirable for connectors to include a device enabling continuity to be checked at any time.

Detector terminations shall be marked.

SECTION THREE — CHARACTERISTICS

9. General

The list below gives the data which, where applicable, shall be supplied by the manufacturer.

9.1 *Characteristics of detectors*

9.1.1 *Mechanical data*

An outline drawing shall be supplied.

Dimensions:

— length;
— diameter;
— weight;
— position of sensitive volume.

Principal materials:

— metals;
— insulators;
— sensitive lining (type and amount);
— major impurities. *

Temperature:

— range of normal operation;
— maximum permissible value.

Filling gas:

— analysis of main constituents;
— pressure.

External pressure:

— maximum permissible value.

Shock and vibration:

— limit values.

9.1.2 *Electrical and nuclear data*

Mode of operation.

Polarizing voltages:

— polarity;
— recommended operating value or values;
— maximum permissible value or values.

Compensation conditions:

— compensation voltage polarity, recommended value and permissible range;
— compensation factor.

* In particular, elements which may cause excessive parasitic detector signals, post-irradiation activity in the detector body and thermal neutron absorption.

Capacitances and insulation resistances:

— electrode to electrode
— electrodes to casing
— casing to frame or interference shielding

} as a function of temperature.

Electric charge delivered per ionizing event for both the radiation to be measured and the main concomitant radiation.

Charge collection time.

Sensitivity:

— pulse mode;
— current mode;
— mean square mode (fluctuations).

Range of measurement.

Influenceability:

— pulse mode;
— current mode;
— mean square mode (fluctuations).

Background signal (an undesired signal produced by natural or induced radioactivity in the materials of the detector):

— initially;
— after a given period in a known neutron flux.

Maximum permissible neutron fluence rate (flux).

Maximum permissible gamma exposure rate.

Sensitive material:

— type;
— purity.

Burn-up life.

Useful life:

— the detector manufacturer shall also supply the test data produced by the tests described in this standard.

9.2 *Characteristics of connectors*

9.2.1 *Mechanical data*

The physical quantities mentioned in Sub-clause 9.1 and applicable to connectors shall be specified as such by the manufacturer.

Particularly important factors are:

	Plug	Socket
Dimensions	Outside diameter Coupling description Centre conductor dimensions Overall length	Outside diameter Coupling description Dimensions for mating plug and pin Overall length
Materials	Body Centre pin Insulation	Body Centre pin Insulation

9.2.2 *Electrical characteristics*

Characteristic impedance and leakage resistance at rated temperature and nominal conditions of use.

Maximum ratings:

— voltage between electrodes and between electrodes and the casing;
— temperature;
— external pressure;
— ambient humidity.

9.3 *Characteristics of cables*

9.3.1 *Mechanical data*

Dimensions:

— outside diameter;
— centre conductor diameter;
— length;
— minimum bending radius;
— weight.

Materials:

— inner conductor;
— outer screens;
— insulation.

9.3.2 *Electrical characteristics*

— leakage resistance (minimum) at rated temperature and humidity;
— capacitance per unit length;
— characteristic impedance and pulse attenuation (where applicable);
— any nuclear limitations on use.

Maximum ratings:

— voltage between conductors;
— temperature;
— external pressure;
— ambient humidity.

10. **Pulse mode neutron detectors**

10.1 *Principles*

Pulse mode neutron detectors include the fission pulse ionization chamber, the boron trifluoride counter tube, the boron-lined counter tube and the helium-3 proportional counter tube.

a) Fission ionization chambers contain a fissile element—for example, uranium 235 whose nuclei, after capturing neutrons, disintegrate into "fission fragments". The latter have considerable kinetic energy which is partly expended in the filling gas to produce ionization.

Fission chambers can be utilized in pulse counting assemblies, in mean current measuring assemblies or in mean square current measuring assemblies (fluctuations).

b) Boron trifluoride counter tubes are thermal neutron detectors which use the reaction:

$$^{10}_{5}B + ^{1}_{0}n_{th} \rightarrow ^{4}_{2}He + ^{7}_{3}Li$$

in the boron trifluoride filling gas. The ionization due to the alpha particle and lithium nucleus is multiplied by an electric field and the counter tube is operated under proportional conditions.

c) Boron-lined counter tubes also use the nuclear reaction of thermal neutrons with boron which is deposited in the form of a solid lining on the inside of the counter wall. The filling gas can therefore be chosen to obtain other required characteristics such as a particular collection time.

d) Helium-3 proportional counters are thermal neutron detectors which use the reaction of the neutron in the gas helium-3.

$$^{3}_{2}He + ^{1}_{0}n_{th} \rightarrow ^{1}_{1}H + ^{3}_{1}H$$

10.2 *Sensitivity in the linear range*

The sensitivity of a pulse mode neutron detector is determined by dividing the mean counting rate, excluding background, by the thermal neutron fluence rate (flux) at the detector. It is specified in units of counts per second per unit neutron fluence rate (flux) (counts $n^{-1} \cdot cm^2$). This sensitivity must be measured with defined electrical characteristics in the detector and the measuring sub-assembly, and it must be stated whether the neutron fluence rate is perturbed or unperturbed.

10.3 *Range of measurement*

The theoretical range of measurement of the detector is determined by its lower and upper limits. The lower limit is fixed for the pulse fission chamber by "alpha pile-up" and by the background due to spontaneous fissions. The upper limit depends on the resolving time, which is a function of the charge collection time and the electrical characteristics of the measuring sub-assembly.

In practice, the lower operating limit may be set by other factors such as counting statistics, gamma radiation and amplifier noise. The practical limitations are explained in Clause 7.

10.4 *Effect of gamma radiation*

The presence of gamma radiation is indicated by the degradation of the pulse spectrum, the bias plateau length and, in certain cases, by the reduction of the multiplication factor of proportional counter tubes.

10.5 *Operating temperature*

The range of operating temperatures is determined by the structural materials and the technology of manufacture. At high temperature, the principal problem is to maintain satisfactory insulator performance.

10.6 *Burn-up and useful life (see definitions in Sub-clauses 2.7 and 2.8)*

The burn-up life depends on consumption of the sensitive material. It is measured by the number of counted events or by the value of the neutron fluence corresponding to a specified quantity of sensitive material consumed.

The useful life depends on the ambient conditions and the influence quantities.

If storage conditions can affect the useful life of the detector, they must be clearly defined.

10.7 *Polarization voltage*

The polarization voltage is defined by polarity and magnitude. In the pulse mode, the polarization voltage of the chamber is commonly a positive voltage applied to the collecting electrode relative to the case.

For proportional counters, the multiplication factor depends on the value of the polarization voltage. The curves characterizing the relationship shall be given by the manufacturer.

For some types of detectors, the characteristics of the measuring sub-assembly and the required life of the detector should be taken into account when selecting the operating polarization voltage.

10.8 *Response to a nuclear event*

The mean electrical charge developed per event in the detector must be known. It is expressed in coulombs. In the case of a proportional counter tube, this variable is a function of the multiplication factor and may be difficult to measure.

The charge collection times and the pulse output current are also important data.

10.9 *Insulation resistance*

For the range of specified temperature, pressure and voltage, the insulation resistance shall have a sufficiently high resistance to restrict leakage current to a reasonable value and shall be free from the pulse breakdown effect, i.e. the generation of spurious pulses which can simulate signal pulses.

For detectors and any associated connector and cable which will operate at high temperature, attention shall be given to variation of the insulation resistance with temperature.

10.10 *Electrical capacitance*

The electrical capacitance is an important characteristic when it has an appreciable effect on the time constant of the input circuit of the measuring sub-assembly.

11. Current mode neutron detectors

11.1 *Principles*

Current detectors include the fission ionization chamber, the boron ionization chamber and ionization chambers sensitive to gamma radiation.

a) Fission current ionization chambers (see item *a)* of Sub-clause 10.1).

b) Boron current ionization chambers. These are thermal neutron detectors which use the reaction:

$$^{10}_{5}B + ^{1}_{0}n_{th} \rightarrow ^{4}_{2}He + ^{7}_{3}Li$$

A great part of the ionization charge caused by the alpha particle and the recoil of the lithium nucleus in the filling gas is collected as a current, whose mean value is generally measured. These chambers may also be used in the mean square current mode.

Boron is utilized in these chambers in the form of a solid lining on the electrodes or sometimes in the form of a gaseous compound.

To reduce the influence of gamma radiation, compensated chambers use the measuring principle of current difference. They generally comprise two nearly identical chambers. One contains a sensitive lining and collects the charge produced by ionization due to the effects of both neutron and gamma radiation, while the other collects only the charge produced by the effect of gamma radiation.

By choice of the polarity of the polarization voltages, the output currents of these chambers are made to oppose each other so that the net output from the detector is essentially due to neutrons.

c) Similar detectors may be used as ionization chambers sensitive to gamma radiation. These differ only from uncompensated boron ionization chambers in the omission of the neutron sensitive material. They can be tested in a similar way

11.2 *Sensitivity in the linear range*

As has been stated in Sub-clause 2.2, the neutron and gamma sensitivity of current detectors (S_n and S_γ) is determined by dividing the mean or mean square output current by the perturbed thermal neutron fluence rate (flux) or gamma exposure rate with a specified energy spectrum in the detector. For d.c. measurements, it is specified in units of current per unit of neutron or gamma flux density ($A \cdot n^{-1} \cdot cm^2 \cdot s$ or $A \cdot R^{-1} \cdot h$).

11.3 *Range of measurement*

The theoretical range of measurement appropriate to the detector is determined by its lower and upper limits.

The lower limit is fixed by parasitic current due to chamber activation, insulation leakage or background alpha curren^t in the case of a fission chamber.

The upper limit is fixed by recombination effects.

The practical limitations are explained in Clause 7.

11.4 *Influenceability by concomitant radiation*

For neutron detectors, the main concomitant radiation to be considered is gamma radiation.

Influenceability is determined by dividing the output current due to gamma radiation alone by the value of the exposure rate which produces this current. It is measured in $A \cdot R^{-1} \cdot h$. For a compensated chamber, the influenceability is reduced by the compensation factor.

If I_γ is the current delivered by an uncompensated chamber in the presence of gamma radiation, the current delivered by an identical but compensated chamber would be $I_\gamma \cdot f$, where $I_\gamma \cdot f$ is the product of I_γ and the compensation factor f.

For gamma ionization chambers, the concomitant radiations to be considered are neutron flux and induced gamma radiations.

11.5 *Operating temperature*

The range of operating temperature is determined mainly by the structural materials and the technology of manufacture. At high temperature, the principal problem is to maintain satisfactory insulator performance.

11.6 *Burn-up and useful life (see definition in Sub-clauses 2.7 and 2.8)*

The burn-up life depends on consumption of the sensitive material. It is measured by the total output charge or by the value of the neutron fluence corresponding to a specified quantity of sensitive material consumed.

The useful life depends on the ambient conditions and the influence quantities. If storage conditions can affect the useful life of the detector, they must be clearly defined.

11.7 *Polarization voltages*

The polarization voltages are defined by polarity and magnitude.

The compensation voltage is usually negative with respect to the chamber case and may be adjustable or fixed, depending on the design of the chamber.

The main polarization voltage is generally positive with respect to the chamber case and is chosen to ensure saturation of the chamber over the operating range. This choice shall be based on data furnished by the saturation curves.

Polarization characteristics for the detector shall be furnished by the manufacturer to allow proper determination of voltage regulation requirements.

11.8 *Response to a nuclear event*

In some applications, the mean and mean square electric charge released per detected neutron or gamma photon is of interest. For mean square measurements, the electron and ion collection time is also important.

11.9 *Insulation resistance*

The insulation resistance of the collector electrode shall be such that leakage current does not introduce significant error within the measurement range. The value chosen shall be related to the performance of the measuring sub-assembly.

11.10 *Electrical capacitance*

The electrical capacitance is an important characteristic when it has an appreciable effect on the time constant of the input circuit of the measuring sub-assembly.

SECTION FOUR — TEST METHODS

12. **General**

12.1 *Introduction*

The tests specified are final tests in the production process. They shall be performed by the manufacturer on each detector and its cable (if the cable is an integral part of the detector) except where the detector is in large quantity production. In this case, the tests shall be performed on an adequate sample.

The test methods described in this standard relate to electrical, nuclear and mechanical characteristics and serve as the basis for acceptance of production detectors.

Wherever neutron or gamma radiation tests involving detector sensitivity, compensation, activation, influence-ability, etc., are required, the energy spectrum and intensity of the radiation should be specified. For these tests, a known isotropic fluence rate or gamma radiation rate is necessary.

Certain special or additional tests should be carried out on prototypes or on detectors selected at random from a batch.

Examples of these special tests are: burn-up and useful life, long-term stability at maximum temperature, influence-ability of pulse fission ionization chambers, high-stress mechanical tests, variation of neutron sensitivity with temperature, vibration, saturation characteristics at high neutron fluence rate (flux) or gamma level. This information should be available from the manufacturer.

12.2 *Choice of test methods*

In selecting test methods, consideration should be given to the fact that detectors for the instrumentation and protection of reactors are designed primarily for relative measurements of nuclear radiation and not for absolute measurements.

Test methods used shall be such that the results are not influenced by electrical interference.

12.3 *List of typical tests*

The following tests should be carried out wherever they are applicable:

a) Mechanical tests:

— microphony.

b) Electrical tests:

— insulation resistance;

— dielectric strength;

— electrical capacity;

— background.

c) Nuclear tests:

— sensitivity;

— influenceability;

— compensation;

— saturation voltage or counts plateau;

— charge developed per event;

— collection time;

— discrimination curve or pulse spectrum;

— multiplication factor.

d) Special tests: may be required by the particular detector specification.

12.4 *Climatic conditions*

Unless otherwise specified, the tests shall be carried out under the following conditions (see also Sub-clause 12.2):

— ambient temperature: 25 ± 15 °C;

— relative humidity: between 45% and 75%.

The actual atmospheric conditions shall be stated on the test sheets. In accordance with good practice, they shall not be subject to large or rapid variations during a series of tests. A practical method for avoiding such variations is to place the detector in a climatic chamber at constant temperature.

12.5 *Mechanical tests*

Mechanical tests should be performed first and then followed by the electrical and nuclear tests.

The mechanical tests shall comprise at least a visual inspection supplemented by such tests as are required for the specific application.

Vibration and impact tests shall be performed on a prototype according to specifications.

13. Specific tests for pulse fission ionization chambers

13.1 *General*

These tests shall be carried out when the detector sub-assembly is complete in all respects including connectors and integral cables. They may form the basis of final acceptance.

The equipment used for all the tests shall comprise suitable measuring instruments which have been accurately set up. It will include a capacitance bridge, appropriate voltage supplies, radiation sources, ovens, etc.

It is necessary that measuring sub-assemblies used for tests should be identified in such a way that their characteristics can be accurately reproduced. In addition, means must be provided to check the calibration at any time either by pulse generators or by a standard chamber.

The important factors are: input circuit type (charge, voltage or current sensitive), input circuit impedance, overall frequency response, input level, discriminator dead time, dynamic range and recovery time.

13.2 *Mechanical tests (see Sub-clause 12.5)*

13.3 *Electrical and nuclear tests*

13.3.1 *At ambient temperature*

a) Where possible, the capacitance between the electrodes and between the electrodes and the chamber case shall be measured and the continuity of all connecting cables verified.

b) The leakage current between the chamber case and any additional outer screen shall be measured at a specified voltage.

c) The chamber alpha current plus the leakage current between the electrodes shall be measured over a specified voltage range and, where applicable, the leakage current between the electrodes and the chamber case shall be measured at a specified voltage.

d) The chamber shall be connected to the measuring sub-assembly and a discriminator curve plotted for zero polarizing voltage and for the specified operating polarizing voltage.

The zero voltage curve shall be used to determine that amplifier noise is satisfactory, and the operating voltage curve shall be recorded to define the alpha activity of the chamber.

The effective discriminator level shall be expressed in identifiable units of current or charge. Absolute units are preferable for this purpose although other, non-absolute units such as "ion pairs" are in common use.

e) The chamber shall be exposed to a reproducible perturbed neutron fluence rate (flux) which gives a count rate of at least 10 counts · s^{-1} at the specified operating voltage. A discriminator curve shall be plotted.

f) The polarizing plateau characteristic curve shall be plotted using a selected discriminator level.

g) When required, the mean electron collection time of the chamber shall be measured.

In the case of current pulses (time constant of the measuring circuit much shorter than the collection time), the electron collection time is represented by the pulse base width.* In the case of charge collection (time constant of the measuring circuit much greater than the collection time), the collection time is measured by the resultant pulse rise time as defined in IEC Publication 50(66), I.E.V. 66-10-375.

h) The electric charge or current per pulse at the specified polarizing potential and at a given discriminator level shall be recorded. This may be determined from the characteristics of the pulse or by a special measurement.

13.3.2 *At maximum operating temperature*

This test does not need to be carried out on those chambers whose maximum working temperature shall not exceed 100 °C.

a) The chamber and an appropriate length of cable shall be placed in an oven and the temperature raised to the maximum operating temperature within defined limits. All connecting cables shall be verified for electrical continuity where possible.

The leakage current between the chamber case and any additional outer screen shall be measured at a suitable voltage.

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* The pulse width is defined by the interval of time measured on the straight line parallel to the time axis and between points with an ordinate equal to 10% of the pulse amplitude.

b) The chamber alpha current plus the leakage current between the electrodes shall be measured over a specified voltage range and, where applicable, the leakage current between the electrodes and the chamber case shall be measured at a specified voltage.

c) The chamber shall be connected to the measuring sub-assembly and a discriminator curves plotted for zero polarizing voltage and for the specified operating polarizing voltage.

The zero voltage curve shall be used to determine that amplifier noise is satisfactory, and the operating voltage curve shall be recorded to define the alpha activity of the chamber.

d) The chamber shall be exposed to the same neutron fluence rate (flux) used in Item *e)* of Sub-clause 13.3.1 above and a discriminator curve plotted. The curve shall agree with that obtained in Item *e)* of Sub-clause 13.3.1 within the specified limits.

e) The polarizing plateau characteristic curve shall be plotted using the discriminator level defined after the test under Item *e)* of Sub-clause 13.3.1.

f) When required, the mean electron collection time of the chamber shall be measured.

g) The chamber and its cables shall remain at the maximum operating temperature for not less than 100 h. At the end of this time and while the chamber and its cables are still at this temperature, the tests under Items *a), b), c), d), e), f)* and *g)* of Sub-clause 13.3.2 shall be repeated.

The results obtained shall be the same within the specified limits.

13.3.3 *Repeat tests at ambient temperature*

After the tests at the maximum operating temperature, the sub-assembly shall be allowed to cool to ambient temperature. The tests under Items *a), b), c), d), e), f)* and *g)* of Sub-clause 13.3.1 shall be repeated. The results obtained should remain within the specified limits.

If the tests of Sub-clause 13.3.2 have been omitted because the operating temperature is less than 100 °C, at least 100 h must elapse between the tests of Sub-clauses 13.3.1 and 13.3.3.

13.4 *Neutron sensitivity in the linear range*

The chamber neutron sensitivity at a specified operating voltage shall be determined and expressed in the units given in Sub-clause 10.2. This may be done by measuring the neutron flux density used in Item *e)* of Sub-clause 13.3.1 or by a special measurement.

14. Specified tests for boron trifluoride and boron-lined proportional counter tubes

14.1 *General (see Sub-clause 13.1)*

14.2 *Mechanical tests (see Sub-clause 12.5)*

14.3 *Electrical and nuclear tests*

14.3.1 *At ambient temperature*

a) The leakage current between the anode wire and the counter case shall be measured at a specified voltage.

b) The counter tube shall be exposed to a reproducible perturbed neutron fluence rate (flux) and the output of the measuring sub-assembly amplifier shall be connected to a multi-channel analyser. The polarizing voltage shall be applied to the counter tube and adjusted until the peak of the spectrum on the analyser is at a predetermined position. The applied voltage and the spectrum full width at half-magnitude shall be recorded. For the boron-lined proportional counter tube, other data such as the whole spectrum may be recorded instead of full width at half-magnitude.

c) A polarizing voltage plateau curve shall be plotted at a specified discriminator level.

A discrimination curve should be plotted at a specified polarizing potential.

14.3.2 *At maximum operating temperature*

This test does not need to be carried out on those counter tubes whose maximum working temperature will not exceed 100 °C.

a) The counter tube and an appropriate length of cable shall be placed in an oven and the temperature raised to the maximum operating temperature within defined limits.

b) The tests under Items *a)* and *b)* of Sub-clause 14.3.1 shall be repeated. The results obtained shall be the same within the specified limits.

c) The counter tube and its cables shall remain at the maximum operating temperature for not less than 100 h. At the end of this time and while the counter tube and its cables are still at this temperature, the foregoing tests under Items *a)* and *b)* of Sub-clause 14.3.1 shall be repeated. The results obtained shall be the same within the specified limits.

14.3.3 *Repeat tests at ambient temperature*

After the tests at the maximum operating temperature, the sub-assembly shall be allowed to cool to ambient temperature. The tests under Items *a)* and *b)* of Sub-clause 14.3.1 shall be repeated and the results obtained shall be the same within the specified limits.

If the tests given in Sub-clause 14.3.2 have been omitted because the operating temperature is less than 100 °C, at least 100 h shall elapse between the tests given in Sub-clauses 14.3.1 and 14.3.3.

14.4 *Neutron sensitivity in the linear range*

The counter tube neutron sensitivity at a specified operating voltages shall be determined and expressed in the units given in Sub-clause 10.2. This may be done by measuring the neutron flux density used in Item *b)* of Sub-clause 14.3.1 or by a special measurement.

14.5 *Influenceability by gamma radiation*

For specified applications in which gamma influenceability is particularly important, the following tests should be performed:

The counter tube shall be connected to a specified measuring sub-assembly and exposed to a specified gamma exposure rate. The output count rate should be determined and should be less than a specified value.

For boron trifluoride counter tubes, this test should be repeated after not less than 100 h.

In some applications, the gamma radiation can influence the response of a counter tube to neutrons. In such cases, special tests would then be necessary.

15. Specific tests for helium-3 proportional counter tubes

Details of tests on these detectors are not given because they are similar to the tests applied to boron trifluoride counter tubes.

16. Specified tests for compensated boron current ionization chambers

16.1 *General*

These tests shall be carried out when the detector sub-assembly is complete in all respects including connectors and integral cables. They may form the basis of final acceptance.

The equipment used for the tests shall comprise suitable measuring instruments which have been accurately set up. It will include a capacitance bridge, appropriate voltage supplies, radiation sources, ovens, etc.

16.2 *Mechanical tests (see Sub-clause 12.5)*

16.3 *Electrical tests*

16.3.1 *At ambient temperature*

a) The capacitance between the collector and each of the polarizing voltage electrodes, and between the collector and the chamber case, shall be measured.

All connecting cables shall be verified for electrical continuity.

b) With both polarizing electrodes connected to the chamber case, the leakage current between the collector and the case shall be measured at a specified voltage.

c) With the collector and gamma polarizing electrodes connected to the chamber case, the leakage current between the neutron polarizing electrode and the chamber case shall be measured at a specified voltage.

d) With the collector and neutron polarizing electrodes connected to the chamber case, the leakage current between the gamma polarizing electrode and the chamber case shall be measured at a specified voltage.

e) The leakage current between the chamber casè and any additional outer screen shall be measured at a specified voltage.

16.3.2 *At maximum operating temperature*

This test does not need to be carried out on those chambers whose maximum working temperature does not exceed 100 °C.

a) The chamber and an appropriate length of cable shall be placed in an oven and the temperature raised to the maximum operating temperature within defined limits. All connecting cables shall be verified for electrical continuity.

b) Repeat test under Item *b)* of Sub-clause 16.3.1.

c) Repeat test under Item *c)* of Sub-clause 16.3.1

d) Repeat test under Item *d)* of Sub-clause 16.3.1

e) Repeat test under Item *e)* of Sub-clause 16.3.1

f) With the neutron polarizing electrode connected to the chamber case, the collector current shall be determined as a function of potential applied to the gamma polarizing electrode. The readings obtained should be less than specified values at all potentials up to a specified limit.

g) With the gamma polarizing electrode connected to the chamber case, the collector current shall be determined as a function of potential applied to the neutron polarizing electrode. The readings obtained should be less than specified values at all potentials up to a specified limit.

h) The chamber and its integral cables shall remain at the maximum operating temperature for not less than 100 h. At the end of this time and while the chamber and its integral cables are still at this temperature, the foregoing tests under Items *a)*, *b)*, *c)*, *d)* and *e)* of Sub-clause 16.3.2 shall be repeated. The results obtained shall be the same within specified limits.

16.3.3 *Repeat tests at ambient temperature*

After the tests at maximum operating temperature, the sub-assembly shall be allowed to cool to ambient temperature. The tests under Items *a)*, *b)*, *c)*, *d)* and *e)* of Sub-clause 16.3.1 shall be repeated and the results obtained shall be the same within specified limits.

If the tests given in Sub-clause 16.3.2 have been omitted because the operating temperature is less than 100 °C, at least 100 h must elapse between the tests given in Sub-clauses 16.3.1 and 16.3.3.

16.4 *Nuclear tests*

16.4.1 *Influenceability by gamma radiation and compensation factor*

The chamber shall be exposed to a known gamma exposure rate of known energy spectrum in a stated geometrical relationship with the source. These factors having been chosen with a view to obtaining adequate accuracy in the following tests.

a) A potential U_γ shall be applied to the gamma polarizing electrode and a saturating positive potential shall be applied to the neutron polarizing electrode. Collector current shall be measured for both positive and reverse values of U_γ.

Gamma current in the compensating section of the chamber is given by half the difference between the two collector currents. This current shall be evaluated and plotted as a function of the potential U_γ.

b) A positive potential U_n shall be applied to the neutron polarizing electrode and the collector current shall be measured with positive and reverse operating potentials applied to the gamma polarizing electrode. The current in the neutron section of the chamber is given by half the sum of these two currents. This current shall be evaluated and plotted as a function of the potential U_n.

The voltage at which the current is 90% and 110% of its plateau value shall be determined and designated as $U_{n\ 0.9}$ and $U_{n\ 1.1}$.

An upper limit to the value of U_n which may be applied in this test may be specified lower than that which causes a 10% increase in saturation current, since it is recognized that some ionization chamber assemblies cannot be tested to $U_{n\ 1.1}$ without exceeding their maximum rated voltage

The gamma influenceability of the neutron-sensitive volume shall be determined from the saturation current obtained in this way and the known gamma exposure rate.

c) The compensation factor is given by the difference between the currents given in *a)* and in *b)*, this difference being divided by the current given in *b)*. It shall be determined as a function of U_γ for a specified value of U_n. This should be repeated for specified source to detector geometries.

On some compensated ionization chambers, reversal of the gamma polarizing potential may introduce errors. In such cases, it may be possible to reverse the neutron polarizing potential and to modify the above procedure accordingly.

16.4.2 *Neutron sensitivity in the linear range*

The chamber shall be exposed to a known perturbed stationary neutron flux with negligible gamma radiation. The neutron saturation characteristics of the neutron-sensitive section shall be determined using the method given in Sub-clause 16.4.1

A positive potential U_n shall be applied to the neutron polarizing electrode and the collector current shall be measured with positive and reverse operating potentials applied in turn to the gamma polarizing electrode. The current due to neutrons is given by half the sum of these two currents.

This current shall be evaluated and plotted as a function of the potential U_n.

The voltage at which the current is 90% and 110% of the saturation value shall be determined and designated as $U_{n\ 0.9}$ and $U_{n\ 1.1}$.

An upper limit to the value of U_n which may be applied in this test may be specified for the reason given in Item *b)* of Sub-clause 16.4.1.

From the saturation current and the known neutron fluence rate (flux), the neutron sensitivity of the chamber shall be determined and limits of accuracy shall be stated.

17. Specific tests for uncompensated boron current ionization chambers

17.1 *General (see Sub-clause 16.1)*

The tests on uncompensated chambers are based on those for compensated chambers but are simpler because of the absence of a gamma polarizing electrode.

17.2 *Mechanical tests (see Sub-clause 12.5)*

17.3 *Electrical tests*

17.3.1 *At ambient temperature*

a) The capacitance between the collector and the polarizing electrodes and between the collector and the chamber case shall be measured.

As far as possible, all connecting cables shall be verified for electrical continuity.

b) With the polarizing electrode connected to the chamber case, the leakage current between the collector and the case shall be measured at a specified voltage.

c) With the collector connected to the chamber case, the leakage current between the polarizing electrode and the chamber case shall be measured at a specified voltage.

d) The leakage current between the chamber case and any additional outer screen shall be measured at a specified voltage.

17.3.2 *At maximum operating temperature*

This test does not need to be carried out on those detectors whose maximum working temperature does not exceed 100 °C.

a) The chamber and an appropriate length of cable shall be placed in an oven and the temperature raised to the maximum operating temperature within defined limits.

As far as possible, all connecting cables shall be verified for electrical continuity.

b) With the polarizing electrode connected to the chamber case, the leakage current between the collector and the case shall be measured at a specified voltage.

c) With the collector connected to the chamber case, the leakage current between the polarizing electrode and the chamber case shall be measured at a specified voltage.

d) The leakage current between the chamber case and any additional outer screen shall be measured at a specified voltage.

e) The collector current shall be determined as a function of potential applied to the polarizing electrode.

The readings obtained shall be less than specified values at all potentials up to a specified limit.

f) The chamber and its cables shall remain at the maximum operating temperature for not less than 100 h. At the end of this time, and while the chamber and its integral cables are still at this temperature, the foregoing tests under Items *a)*, *b)*, *c)* and *d)* of Sub-clause 17.3.2 shall be repeated. The results obtained shall be the same within specified limits.

17.3.3 *Repeat tests at ambient temperature*

After the tests at maximum operating temperature, the sub-assembly shall be allowed to cool to ambient temperature. The tests under Items *b)*, *c)* and *d)* of Sub-clause 17.3.1 shall be repeated and the results obtained should be the same within specified limits.

If the tests of Sub-clause 17.3.2 have been omitted because the operating temperature is less than 100 °C, at least 100 h must elapse between the tests of Sub-clauses 17.3.1 and 17.3.3.

17.4 *Nuclear tests*

Neutron sensitivity and influenceability by gamma radiation

The polarization voltage, neutron sensitivity, influenceability by gamma radiation and background for an uncompensated ionization chamber shall be determined by the test methods given in Sub-clauses 16.4.1, 16.4.2 and 16.4.3, as applicable.

18. Specific tests for current ionization chambers for gamma radiation

The tests for current ionization chambers are identical to those for uncompensated boron current ionization chambers except that the primary and concomitant radiations are interchanged.

19. Specific tests for fission current ionization chambers

The tests for fission current ionization chambers are identical to those for uncompensated boron current ionization chambers. Alpha activity of the chamber coating will, however, influence leakage current measurements and should be taken into consideration. It will influence the tests under Items *b)* and *c)* of Sub-clauses 17.3.1 and 17.3.2 as well as Sub-clause 17.3.3, and may also cause errors in the primary and concomitant sensitivity measurements unless adequate radiation strengths are used.